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# Designing Instruction That Supports Cognitive Learning Processes

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***Objective:*** To provide an overview of current cognitive learning processes, including a summary of research that supports the use of specific instructional methods to foster those processes. We have developed examples in athletic training education to help illustrate these methods where appropriate.

***Data Sources:*** Sources used to compile this information included knowledge base and oral and didactic presentations.

***Data Synthesis:*** Research in educational psychology within the past 15 years has provided many principles for designing instruction that mediates the cognitive processes of learning. These include attention, management of cognitive load, rehearsal in working memory, and retrieval of new knowledge from long-term memory. By organizing instruction in the context of tasks performed by athletic trainers, transfer of learning and learner motivation are enhanced.

***Conclusions/Recommendations:*** Scientific evidence supports instructional methods that can be incorporated into lesson design and improve learning by managing cognitive load in working memory, stimulating encoding into long-term memory, and supporting transfer of learning.

***Key Words:*** transfer of learning, job analysis, cognitive overload, instructional systems design

The goal of instructional programs for professionals such as athletic trainers is to build knowledge and skills that can be transferred to the career field after learning. To achieve this goal, instruction must be designed to maximize human cognitive processes that result in learning and minimize those that disrupt learning. Research in cognitive models of learning and instruction over the past 20 years has revealed a number of relevant techniques and processes to achieve this goal. Many of these instructional innovations are particularly relevant for building problem-solving skills in knowledge workers. In this article, we provide an overview of current cognitive learning processes, including a summary of research that supports the use of specific instructional methods to foster those processes. We have developed examples in athletic training education to help illustrate these methods where appropriate.

The premise behind our discussion is that instruction is a design science. Design sciences such as engineering or information-systems design include professions in which products are developed to meet practical goals. In the case of instructional science, the products are learners who acquire specific skills in efficient and effective ways that improve professional performance. Design-science professionals draw on scientific principles and creative inspiration to develop new products. The research in instructional psychology over the past 15 years provides a good start to a scientific foundation for design of effective instruction.[1–3]

For the training of business and military workers, instructional-systems design (ISD) processes are applied by teaching knowledge and skills derived from an analysis of job duties most important to organizational success. Training of professionals in business and industry for everything from sales to information technology consumes about $56 billion of resources per year in the United States.[4] A systematic approach to instruction helps ensure a return on this investment. Figure 1 illustrates a typical ISD process that defines a learning need, completes an analysis of the job (task analysis), designs the training program around the job analysis, develops instructional materials, and evaluates the learning outcomes for revision.

The academic community has more commonly used content analysis as the basis for organization and development of courses. In the last 25 years, some schools of medicine followed the lead of McMasters by shifting their curriculum from content-oriented courses (eg, anatomy, pathology) to courses that use medical case studies as the basis for instruction.[5] This new approach is called problem-based learning. Problem-based learning students have been reported to be more highly motivated, better at problem solving, and better able to apply basic science knowledge to the solution of clinical problems than those in traditional medical education.[5] We suggest that, for educating professionals such as athletic trainers, the use of critical job tasks as a basis for lesson design and development has some advantages in supporting transfer of instruction and in maximizing the relevance of the instructional environment, which, in turn, increases the interest and learning of students.[6,7]

## COGNITIVE LEARNING MODELS

Current theories of learning are based on the interaction among 3 memory systems and the processes that move information among them.

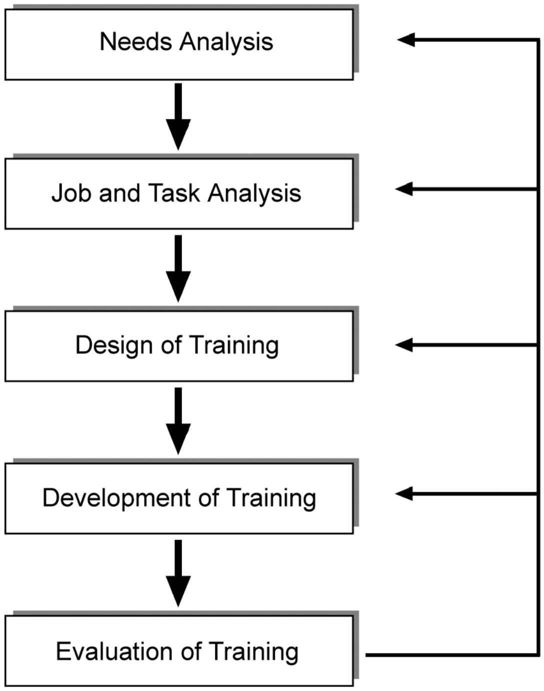


**Figure 1. The instructional-systems design process.**

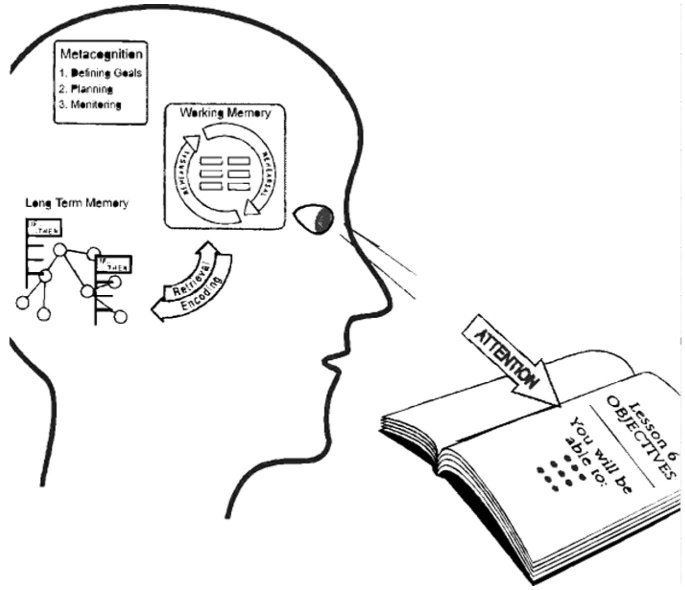


**Figure 2. Cognitive processes that mediate learning.**

## Three Memory Systems

The 3 memory systems are the visual and auditory sensory memories, working or short-term memory, and long-term memory. First, data from the eyes and ears are temporarily stored in visual and auditory sensory memory, and then they move into working (short-term) memory. Working memory is a limited-capacity processor that includes separate storage for auditory and visual information. One landmark in the development of cognitive psychology was the classic paper by Miller, who referred to the capacity of working memory as ''7 plus or minus 2.''[8] Working memory, while limited in capacity, is the central processor for learning and thinking. For learning to occur, new sensory information from the visual and auditory systems must be integrated in working memory to form a coherent idea. Then these ideas must be rehearsed in working memory in a way that integrates new ideas into existing memories (called schemas) in long-term memory. The integration of new data into existing schemas is called encoding. Long-term memory has a large storage capacity. However, encoding into long-term memory is not sufficient. Because all processing takes place in working memory, the new knowledge and skills encoded into long-term memory must be retrieved into working memory when needed to perform a skill or task. This final stage is the cognitive basis for transfer of learning.

## Cognitive Processes Involved in Learning: Overview

Clark[7] described several critical processes that mediate the processes behind transformation of sensory data into retrievable knowledge in long-term memory (Figure 2). They include attention, rehearsal in working memory, retrieval from long-term memory, and metacognitive monitoring. Because working memory has a limited capacity and accepts data from the environment and from long-term memory, attention is the psychological mechanism used to narrow incoming information to accommodate limits of working memory. It is important that student attention be focused on elements in the environment that are relevant to learning and filter out irrelevant elements. Cueing devices, such as arrows or bolding of text in instructional materials, and providing instructional objectives are 2 instructional techniques that support attention.

New sensory data entering working memory from the visual and auditory sensory memories must be integrated first with each other to form coherent ideas, and second, into existing schema in long-term memory. Instructional events that activate relevant prior knowledge in long-term memory and stimulate rehearsal in working memory support these integrations. When new knowledge and skills are needed later on the job, retrieval from long-term memory during learning into working memory is essential to the transfer of learning. Retrieval requires that cues the learner will encounter in the work environment be encoded in new schema at the time of learning. Therefore, a lesson that teaches how to take a blood-pressure measurement must use the blood-pressure equipment during learning so the right cues are available later when the learner needs to take a blood-pressure reading on the job. Finally, metacognition serves as the operating mechanism for learning. Metacognitive skills are responsible for setting learning goals, determining learning strategies, monitoring progress, and making adjustments as needed. Learners with undeveloped metacognitive skills profit from high instructional structure and support in managing and monitoring their learning. For example, frequent skills tests to assess knowledge help these learners spot topics that require additional study.

## Construction of Knowledge

Cognitive models of instruction view learning as a process that requires learners to actively construct new knowledge. The role of instruction is to provide an environment that helps the learner leverage the cognitive processes summarized earlier and minimize their disruption. Specifically, instruction should help the learner to

- Focus attention to elements of the environment relevant to learning,

- Minimize cognitive load in order to use the limited resources of working memory most effectively,
- Rehearse new information in working memory so that it is integrated into existing schemas in long-term memory,
- Retrieve new knowledge when needed after the learning, and
- Manage and monitor the metacognitive learning processes.

In this article, we describe and illustrate several specific instructional processes and methods to support these cognitive processes. Space prohibits a comprehensive discussion of all of the instructional methods recently demonstrated to increase learning. For more details, refer to the books by Clark[7] and Clark and Mayer.[6]

## TRANSFER FAILURE

As previously summarized, simply encoding new knowledge into existing schemas in long-term memory is not sufficient; it must be encoded in such a way that it can be retrieved later when needed. This retrieval process is the psychological basis for transfer of learning. Transfer failure is potentially one of the most costly gaps in the training of workers and the education process in general. And transfer continues to be a challenging area for research in instructional psychology.[9]

### Inert Knowledge

One cause of transfer failure is inert knowledge. Inert knowledge refers to information that is stored in long-term memory, but because this information lacks the appropriate cues for retrieval, it fails to transfer. For example, a student makes an A in geometry but fails to use the principles of geometry, when appropriate, to learn goniometry. This also is relevant to the principles and concepts learned in physics or biomechanics and applying them to rehabilitation. In these situations, the skills have been encoded into long-term memory, but the retrieval cues that support their transfer have not. One question that researchers have asked is how instruction can improve transfer of fundamental principles and theory to activities of the profession.

### Near- and Far-Transfer Tasks

Most professional work includes 2 types of tasks: near and far transfer. A near-transfer task is one that is performed more or less the same way each time by following a series of prescribed steps. These tasks are procedural. Taking a blood-pressure measurement or disinfecting a whirlpool are examples of near-transfer tasks performed by athletic trainers.

In contrast, far-transfer tasks do not have one invariant approach. The practitioner must assess the environment and use judgment to adapt guidelines when performing far-transfer tasks. Some examples in athletic training include designing a rehabilitation program and assessing an injury. Although there is a specified process in assessing an injury, the critical interpretations of signs and symptoms and decisions made in response represent far-transfer tasks. The instructional methods to ensure transfer differ between near- and far-transfer tasks; therefore, distinction between the 2 types of tasks is important.

In order to minimize inert knowledge, the instruction should be organized around the critical tasks—both near and far transfer—the athletic trainer must perform. In that way, the new knowledge and skills will be learned in a context of retrieval in the professional performance environment. This suggests that lessons and activities within a course should be organized around athletic trainers' tasks so that the critical retrieval cues are present during learning.

### Job Analysis and Taxonomies of Instruction

Transfer of learning is more likely when new knowledge and skills are acquired in their context of application. In the case of the athletic training student, the near- and far-transfer tasks provide a context for applying knowledge and skills learned in instruction. To incorporate case studies and examples based on job tasks requires that a job analysis supplement content analysis. One common approach to job analysis begins by defining the major functions of the job and then breaks each function into subfunctions and subfunctions into tasks. Course lessons, examples, and case studies are developed on the basis of these tasks to provide authentic environments for applying new knowledge and skills. For example, in Figure 3, we show a partial job analysis for an athletic trainer.[10] In this example, the main job functions for the athletic trainer are formulated from the competency areas delineated in the *Athletic Training Educational Competencies.*[11]

As the tasks are defined, they are categorized as near (procedural) or far (principle) transfer. If they are near transfer, the steps are defined. The steps to perform common procedural tasks are typically documented in standard texts for athletic training. In our job analysis for athletic trainers (see Figure 3), the procedures for auscultation of the lungs are listed along with the associated knowledge needed to perform these procedures. For tasks that are far transfer, guidelines (rather than steps) are documented. Unlike steps, guidelines leave more room for interpretation and are applied on the job in different ways depending on the situation. For example, when designing and advancing rehabilitation programs, there are guidelines to follow based on variables such as healing time. However, the athletic trainer must use his or her judgment and consider many variables (such as pain, muscle function, swelling, etc) collectively when making a decision about advancing a patient in the rehabilitation progression. This explains the difficulty novices have in applying their cognitive knowledge to the clinical application of rehabilitation after injury.

### Cognitive Task Analysis

Guidelines of far-transfer tasks are more difficult to define than steps of near-transfer tasks. In some career fields, such as sales, observations of proficient practitioners engaged in performing far-transfer tasks can reveal the underlying guidelines. However, in other career fields, such as information technology, observations yield little because the critical actions are mental and the most important aspects of the task are invisible. While traditional textbooks refer to processes to perform far-transfer tasks such as injury assessment, in most cases the mental judgments behind activities such as assessing an injury are not explicitly stated. It is only in recent years that the dominance of knowledge work has revealed the gap in many instructional materials that treat most tasks as procedures. In response, cognitive techniques of task analysis have been used to identify the thoughts and decisions that underlie far transfer skills.

One example is a specialized interview technique called Prerequisites, Actions, Responses, Interpretations (PARI) that

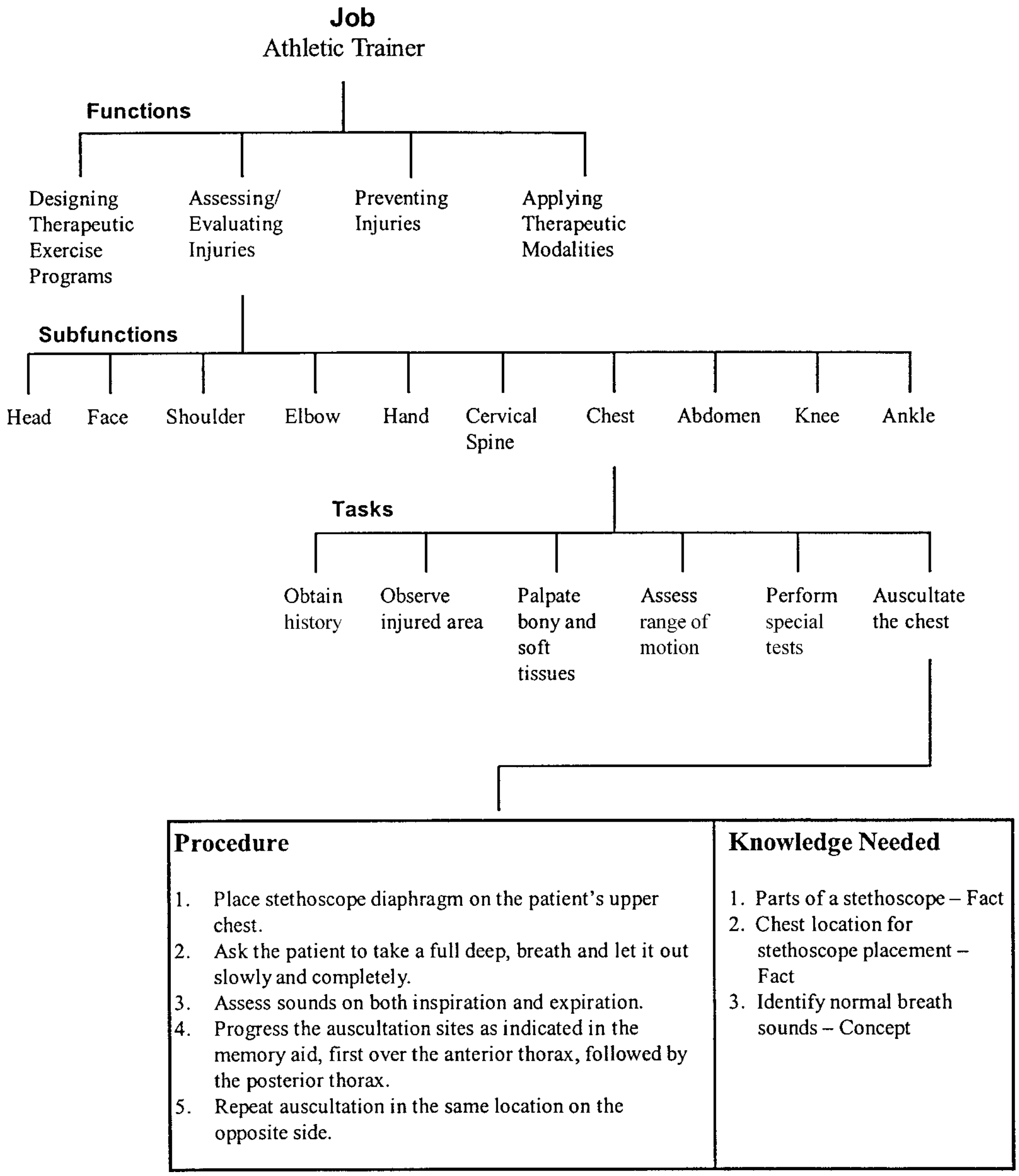


**Figure 3. Partial job analysis for an athletic trainer. Procedure information adapted from O'Conner DP, *Clinical Pathology for Athletic Trainers Recognizing Systemic Disease,* 2001, with permission from Slack Inc.**[10]

is used to define the thoughts experts have while solving a problem. Specifically, the interview seeks to define the prerequisites, actions, responses, and interpretations that experts have in their mind as they solve a problem. Table 1 illustrates part of a PARI interview from an analysis of intensive-care nurses doing patient assessment.[12]

After the guidelines and steps to perform job tasks are defined, the knowledge required to perform the tasks is identified. Typically, this knowledge is of 3 types: facts, concepts, and processes. Thus, the completed job analysis results in defining 5 types of knowledge to be included in instruction (Table 2). This taxonomy adapted from Merrill's component display theory[13,14] is effectively used as the basis for the design of instruction for delivery in the classroom or the Internet.[15] As we will see, it serves as a useful taxonomy during the design and development of instructional content because it is based on job analysis, and each type of content has specific instructional methods linked to it.

As an example, in our athletic training job analysis (see Figure 3), most of the content type is facts, except for distinguishing between normal and abnormal breath sounds, which is a concept.

## MANAGING COGNITIVE LOAD IN WORKING MEMORY

After new data from the environment enter working memory, they must be processed. Specifically, auditory and visual data must be integrated into a coherent idea. And new ideas must be integrated with preexisting knowledge stored in long-term memory schemas. All of this processing activity requires capacity in working memory. Because working memory is a limited-capacity processor, instructional techniques that reduce cognitive load have been proven to improve learning effectiveness and efficiency. This is especially true of novice learners, who are most susceptible to cognitive overload.

Numerous load-management techniques have been reported in recent literature.[16] We describe several here, including the

**Table 1. Cognitive Job Analysis Prerequisites, Actions, Responses, Interpretations (PARI) Interview[12]**

| | |
|---|---|
| Interviewer: | Which body system would you start with? |
| Expert: | Neurology system. |
| Interviewer: | Why? |
| Expert: | I want to see if the patient is conscious. |
| Interviewer: | What would you do first? |
| Expert: | I would use my flashlight to examine reaction of the pupils. |
| Interviewer: | The pupils both react equally to the light stimulus by contracting. What does the result imply or mean? How do you interpret this? |
| Expert: | There's no brain damage. . . . |

modality principle, the contiguity principle, the chunking of lessons and placement of practice exercises, and the use of worked examples.

## Modality Principle

Mayer[17] and Clark and Mayer[6] derived a number of principles for the development of lesson materials based on controlled experiments that measured learning from the study of instructional materials (books or multimedia) teaching scientific processes. The modality principle asks the question, ''Is learning better when instructional visuals are described with text or with audio narration?'' A number of experiments in which multimedia lessons teaching scientific processes, such as how lightening forms or how a brake works, used animation explained either by text or by the same words delivered in audio narration. The materials using audio to describe the words resulted in an 80% median gain in learning, for an effect size of 1.17.[17] Mayer[17] concluded that learning is deeper when the limited capacity of working memory is maximized by coordinated inputs into the visual and auditory subsystems rather than just the visual subsystem, as is the case when text is used to describe visuals.

## The Contiguity Principle

When designing instruction materials or Web-based instruction in which bandwidth precludes the use of audio, graphics must be explained by text. In these situations, a number of researchers have shown that integrating the text into the graphic is better than separating the text. For example, if demonstrating a geometry problem solution in text, Sweller et al[18] found that an integrated version, in which the problem steps are placed into the geometry illustration, produced better learning than the same steps placed underneath the illustration. Mayer[17] found similar results with placement of text adjacent to or distant from illustrations in multimedia lessons. From comparisons in 5 experiments, Mayer found a median gain in learning of 68%, with an effect size of 1.12 for lessons that integrated text into illustrations. Less mental effort is involved in integration of pictures and text when they are placed physically close to each other on the page or screen. Mayer referred to this as the contiguity principle of instruction.

## Lesson Size and Practice Distribution

To avoid overload, lesson length or the topic size within lessons should be adjusted based on the background of the audience and the technical difficulty of the material. Novices

**Table 2. Five Content Types**

| Content | Definition | Example |
|---|---|---|
| Fact | Unique, specific data or object. | Normal heart rate is 72 beats/minute. |
| Concept | A category or class of objects or events that can be defined. | Differentiation of particular injuries. |
| Process | A flow of events in a physical, business, or mechanical system. | How blood circulates through the heart and lungs. |
| Procedure | A task that is performed the same way each time. | How to take a blood pressure. |
| Principle | A task that requires judgement when performed. A cause-effect relationship. | Designing and progressing a rehabilitation program. |

learning relatively technical content profit from shorter lessons. Additionally, many studies have shown that regularly spaced practice exercises yield better learning than the same amount of practice completed all at once. According to the National Research Council, ''the so-called spacing effect—that practice sessions spaced in time are superior to massed practices in terms of long-term retention—is one of the most reliable phenomena in human experimental psychology. The effect is robust and appears to hold for verbal materials of all types as well as for motor skills.''[19] For example, consider 2 groups that study the same material and practice for the same length of time (ie, four 20-minute segments). One group spreads its practice over 2 days (morning and afternoon), while the second group practices all at once on the same day. The group with a distributed practice schedule has consistently better long-term retention than the group that practiced only once. This effect is observed only with delayed testing, not on immediate measures of knowledge. Based on cognitive-load theory, it is likely that spaced practice clears the limited capacity of working memory more frequently, freeing it for additional new information.

## Worked Examples

In courses that teach problem solving, such as mathematics, time is saved and learning is improved when learners study worked examples in lieu of working all the problems themselves.[20] Controlled experiments showed that it is best to intersperse practice problems with worked examples.[21] For example, rather than work out 12 problems themselves, the learners study 2 worked examples and then solve a third themselves, followed by studying 2 more worked examples, and so on. The advantage of worked examples decreases as the learners gain more experience in the domain being trained.[22] Worked examples in athletic training can take the form of case studies in which the solution process is described for the student along with an explanation of the thought process. These worked case studies are followed by several examples in which the student must reach a correct conclusion.

The examples we have summarized represent a number of instructional techniques that improve learning by managing cognitive load. Novice learners in particular need such instructional support to help them use the limited resources of their working memory effectively.

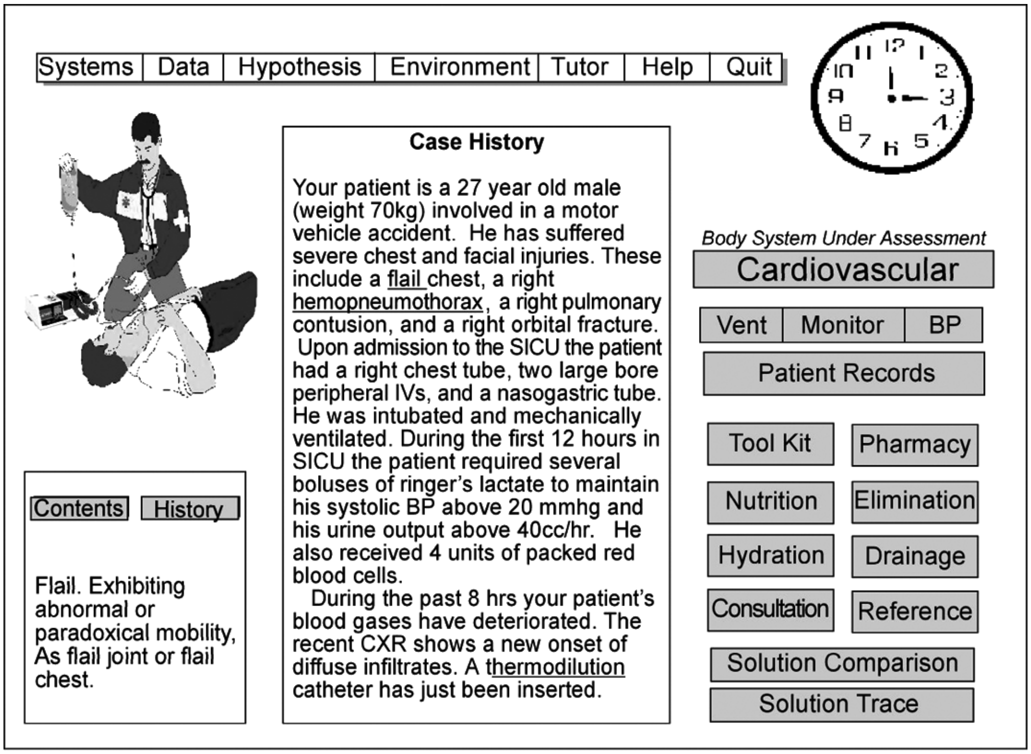


**Figure 4. Course interface designed to teach the decision-making process to intensive-care nurses. Reprinted with permission.**[12]

## PROMOTING ENCODING INTO LONG-TERM MEMORY

The reason for managing cognitive load is to free limited working-memory capacity for the kind of processing that facilitates encoding into long-term memory. Although some learners are good at spontaneously processing new information, many lack this skill and benefit from processing support in the instruction. One important way to support encoding is to include overt processing opportunities during the instruction in the form of practice exercises, including case studies, group projects, and short-answer exercises. As discussed earlier, it is important to schedule these at frequent intervals and, to maximize transfer, to incorporate as many cues for the work tasks as possible.

### Practice for Near- and Far-Transfer Tasks

We distinguish 2 types of tasks performed by athletic trainers: procedural tasks (near transfer) and principle tasks (far transfer). Procedural-task practice is the easiest to plan, although its implementation requires job tools and resources. For example, if teaching novice athletic training students how to take blood-pressure measurements, you would list the procedural steps, provide a demonstration, and have the students follow the procedures using actual tools. Additionally, you would use a similar method to teach the near-transfer steps for auscultation of the lungs in our job-analysis example.

Because there is no one correct way to perform far-transfer tasks, arranging appropriate practice requires greater creativity. Research has shown that to build the robust schemas needed for far-transfer tasks, learners need opportunities to study several problems whose solutions are based on the same principles but whose surface features differ.[23] For example, students can be given case studies that deal with evaluating a conscious athlete with a head injury. In each case, signs and symptoms can be changed to give the students different perspectives that may occur with a given injury. The goal is to help learners build a mental model to apply to the many diverse professional situations they will encounter. Typically, some form of case study or simulation is used. If possible, learners should work in groups and prepare solutions to be presented to the class. The instructor can facilitate discussions of the tradeoffs in the different solutions reported. For instance, if 4 groups of students are given the same case study for rehabilitation after an elbow injury, the 4 different approaches to the treatment plan allow students to see different perspectives. The instructor could use class time to facilitate a discussion around the tradeoffs of each. In more complex instructional environments, simulation using multimedia or simulators allows the learners to try out their solutions and learn from the results.

To illustrate this approach, we describe multimedia instruction developed to help intensive-care nurses assess patients and take appropriate actions. Based on the cognitive task analysis for intensive-care nurses we described earlier, the research team developed a multimedia lesson in which nurses solve a variety of patient cases. Figure 4 illustrates the course interface designed to teach the decision-making processes derived from the job-analysis assessment.[12]

The students are given the case study shown in the center of the screen. They are provided with buttons that allow them to take various actions, such as checking vital signs, performing tests, or administering medications. As they collect patient data, they can select from a menu list of hypotheses. The system records the students' solution actions, which can be compared with experts' solution actions at any time. Although this system has yet to be evaluated, with an instructional system designed along similar lines to teach troubleshooting of electric equipment, learners spending 25 hours in instruction

| | Fact | Concept | Process | Procedure | Principle |
|---|---|---|---|---|---|
| **Use** | | Identify a new instance; Discrimination | Solve a problem; Make a prediction | Perform a task | Perform a task; Solve a problem |
| **Remember** | State Facts | State Definition | Describe the Stages | List the Steps | List the Guidelines |

**Figure 5. The content-performance matrix.**

gained the expertise of 4-year practitioners.[24] Although this seems like magic, most of this acceleration of expertise is due to time compression of experience through simulations. Twenty-five hours in the tutorial provides the equivalent of 4 years of experience on the job, with the advantage of learning in a structured progression of case exercises. While there are some written simulations available for athletic training students, they are more linear in nature and do not contain the robustness of other simulation products available in medicine or business.

## Practice for Supporting Knowledge

We previously summarized our version of Merrill's component display theory.[13,14] In addition to the main job tasks that are either procedures or principles, lessons must also teach associated knowledge, including facts, concepts, and processes. Figure 5 illustrates these 5 content types at 2 levels of performance. The ''remember'' level requires recall of the content. The ''use'' level requires application of the content. We recommend that instructional exercises be written at the ''use'' level because the rehearsals prompted by use involve practices similar to those required on the job. Therefore, they build more transferable knowledge in long-term memory. For instance, when learning how to take a blood-pressure measurement, the student can practice either by listing the steps to take a measurement or by actually taking one. Clearly, performing the task yields better learning than describing how to perform it.

To practice concepts at the ''use'' level, we recommend exercises that promote discrimination of new concepts. Rather than giving a definition of a concept, the learner identifies an instance of one not previously seen. For example, upon hearing tapes of lung sounds, the learner identifies normal lung sounds, or given several photographs of different injuries that all have similar characteristics, the student identifies the requested injury and explains why the photograph is correct. To practice processes, the instruction should include some kind of case or exercise that requires the learner to solve a problem or make a prediction based on that process or a malfunction of that process. For instance, if one is teaching the therapeutic effects of moist heat, the student should be able to explain the normal physiologic processes before the application of the heat to the area and how the normal physiologic processes change as a result of heat being applied and predict what will happen and explain the physiologic rationale if the heat is applied to an acute injury.

Notice on the content-performance matrix (Figure 5) that the cell for ''facts'' at the use level is blocked out. This is because there are no ways to process facts at the use level; they can only be memorized. Because human memory is poor, we recommend that factual information be placed on a learning aid and used in conjunction with the task that would require it. For example, in auscultation of the lungs, the stethoscope placement could be indicated with a diagram. Over a period of time, the student would no longer need the learning aid as the landmarks become encoded into long-term memory through repetition.

In some cases, however, factual information must be accessed quickly and a working aid is inappropriate. This is often true in safety-critical situations requiring an immediate response. In these situations, drill and practice are needed to automate the skill in long-term memory. We know any skill practiced for hundreds of times becomes ''hard wired,'' or automated, in long-term memory. Once automated, a skill does not require the resources of working memory. In most cases, automation occurs naturally during job-task repetitions, yet sometimes it must be achieved during instruction because the real world requires a fast and accurate response. In these cases, drill and practice must occur over many hundreds of trials. This is particularly true for low-frequency, high-risk situations the athletic trainer may encounter. Some examples from athletic training include assessment of an unconscious athlete, determining the need for and performing rescue breathing and cardiopulmonary resuscitation, and other emergency situations.

We suggest that instruction for professionals such as athletic trainers should use instructional methods that support human learning processes, including attention, management of cognitive load, rehearsal in working memory, and retrieval of new knowledge from long-term memory. Educational psychology research in the past 15 years has provided many principles for designing instruction that mediates these processes. We recommend the use of the instructional taxonomy called the content-performance matrix to define job content as fact, concept, process, procedure, or principle. Our goal was not to provide an exhaustive accounting of the many diverse learning methods associated with cognitive processes or with the content-performance matrix; rather, we provide an overview of these methods and references for those interested in further reading.

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